Updated Status of Federally Listed ESUs of West Coast Salmon and Steelhead

West Coast Salmon Biological Review Team

Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, WA 98112

Southwest Fisheries Science Center
Santa Cruz Laboratory
110 Shaffer Road
Santa Cruz, CA 95060

July 2003

TABLE OF CONTENTS

ACKNOWLEDGMENTS

We are grateful to the large number of regional biologists who provided raw data and information used in this report. This report was improved as a result of comments provided by state, tribal, and federal comanagers on an earlier draft. The effort to update the status of all listed ESUs of west coast salmon and steelhead would not have been possible without the help of many, including Andrew Albaugh, Charlene Bergeron, Ronda Carbary, Henry Carson, Kurt Davis, Christopher Donohoe, Tamara Harms, Christine Holt, Andrea Jarvela, Laura Johnston, Jenny Moslemi, Jessica Piasecke, Cory Ruedebusch, Brycen Swart, JJ Westfall, and Thomas Williams.

EXECUTIVE SUMMARY

During the 1990s, the National Marine Fisheries Service (NMFS; NOAA Fisheries) conducted a series of reviews of the status of West Coast populations of Pacific salmon and steelhead (*Oncorhynchus* spp.) with respect to the U.S. Endangered Species Act (ESA). This report summarizes scientific conclusions of the NMFS Biological Review Team (BRT) regarding the updated status of 26 ESA-listed ESUs of salmon and steelhead (and one candidate species ESU) from Washington, Oregon, Idaho, and California. These ESUs were listed following a series of status reviews conducted during the 1990s. The status review updates were undertaken to allow consideration of new data that accumulated over the various time periods since the last updates and to address issues raised in recent court cases regarding the ESA status of hatchery fish and resident (nonanadromous) populations.

This report represents the first major step in the agency's efforts to review and update the listing determinations for all listed ESUs of salmon and steelhead. By statute, ESA listing determinations must take into consideration not only the best scientific information available, but also those efforts being made to protect the species. After receiving the BRT report and considering the conservation benefits of protective efforts, NMFS will determine what changes, if any, to propose to the listing status of the affected ESUs.

As in the past, the BRT used a risk-matrix method to quantify risks in different categories within each ESU. In the current report, the method was modified to reflect the four major criteria identified in the NMFS viable salmonid populations (VSP) document (McElhany et al. 2000): abundance, growth rate/productivity, spatial structure, and diversity. These criteria are being used as a framework for approaching formal ESA recovery planning for salmon and steelhead. Tabulating mean risk scores for each element allowed the BRT to identify the most important concerns for each ESU and to compare relative risk across ESUs and species. The BRT considered these data and other information in making their overall risk assessments. Based on provisions in the draft revised NMFS policy on consideration of artificial propagation in salmon listing determinations, the BRT's risk analyses focused on the viability of populations sustained by natural production.

Based on the criterion of self-sustainability, for the following ESUs the majority BRT conclusion was "in danger of extinction:" Upper Columbia River spring-run chinook, Sacramento River winter-run chinook, Upper Columbia River steelhead, Southern California steelhead, California Central Valley steelhead, Central California Coast coho, Lower Columbia River coho, Snake River sockeye. For the following ESUs, the majority BRT conclusion was "likely to become endangered in the foreseeable future:" Snake River fall-run chinook, Snake River spring/summer-run chinook, Puget Sound chinook, Lower Columbia River chinook, Upper Willamette River chinook, California Coastal chinook, Central Valley spring-run chinook, Snake River steelhead, Lower Columbia River steelhead, Upper Willamette River steelhead, Northern California steelhead, Central California Coast steelhead, South-Central California Coast steelhead, Oregon Coast coho, Southern Oregon/Northern California Coasts coho, Ozette Lake sockeye, Hood Canal summer-run chum, and Lower Columbia River chum. In one case (Middle Columbia River steelhead), the BRT was nearly evenly split on the question of whether the ESU was or was not likely to become endangered in the foreseeable future (a slight majority concluded that the ESU was likely to become endangered) (Table 1).

Table 1. BRT conclusions regarding updated status of salmon and steelhead ESUs; X indicates the majority vote; (X) indicates a substantial minority (>40% of the vote).

Species	ESU	Danger of Extinction	Likely to Become Endangered	Not Likely to Become Endangered
Chinook	Snake River fall-run		X	
	Snake River spring/summer-run		X	
	Upper Columbia River spring-run	X	(X)	
	Puget Sound		X	
	Lower Columbia		X	
	Upper Willamette		X	
	California Coastal		X	
	Sacramento River winter-run	X		
	Central Valley spring-run		X	
Steelhead	Snake River Basin		X	
	Upper Columbia River	X	(X)	
	Middle Columbia River		X	(X)
	Lower Columbia River		X	
	Upper Willamette River		X	
	Northern California		X	
	Central California Coast		X	
	South Central California Coast		X	
	Southern California	X		
	California Central Valley	X		
Coho	Oregon Coast		X	(X)
	Southern Oregon / Northern California Coasts		X	
	Central California	X		
	Lower Columbia	X		
Sockeye	Snake River	X		
	Ozette Lake		X	
Chum	Hood Canal summer-run		X	
	Lower Columbia River		X	

INTRODUCTION

PRIMARY CONTRIBUTORS: ROBIN S. WAPLES AND THOMAS C. WAINWRIGHT (NORTHWEST FISHERIES SCIENCE CENTER)

During the 1990s, the National Marine Fisheries Service (NMFS; NOAA Fisheries) conducted a series of reviews of the status of West Coast populations of Pacific salmon and steelhead (*Oncorhynchus* spp.) with respect to the U.S. Endangered Species Act (ESA). Initially, these reviews were in response to petitions for populations of a particular species within a particular geographic area, but in 1994, the agency began a series of proactive, comprehensive ESA status reviews of all populations of anadromous Pacific salmonids from Washington, Idaho, Oregon, and California (Federal Register, Vol. 59, No. 175, September 12, 1994, p. 46808).

The first step in these reviews is to determine the units that can be considered “species” under the ESA and, hence, listed as threatened or endangered, if warranted, based on their status. The ESA allows listing not only of full species, but also named subspecies and “distinct population segments” (DPSs) of vertebrates (including fish). The ESA petitions and status reviews for Pacific salmonids have focused primarily on the DPS level. To guide DPS evaluations of Pacific salmon, NMFS has used the policy developed in 1991 (NMFS 1991, Waples 1991, 1995), which is described in the next section. As a result of these status reviews, NMFS has identified over 50 evolutionary significant units (ESUs) of salmon and steelhead from California and the Pacific Northwest, of which 26 are listed as threatened or endangered species under the ESA. A complete list of these evaluations can be found at (http://www.nwr.noaa.gov/1salmon/salmesa/fractlist.htm), and the technical documents representing results of the status reviews can be accessed online at web sites of the Northwest Fisheries Science Center (http://www.nwfsc.noaa.gov/pubs/), the Southwest Regional Office (http://swr.nmfs.noaa.gov/salmon.htm), the Santa Cruz Laboratory (http://www.pfeg.noaa.gov/tib/esa/salmonids/esa_docs/index.html), and the Northwest Regional Office (http://www.nwr.noaa.gov/1habcon/habweb/listnwr.htm).

In 2000, NMFS initiated formal ESA recovery planning for listed salmon and steelhead ESUs. Recovery efforts are organized into a series of geographic areas or domains. Within each domain, a technical recovery team (TRT) has been (or is in the process of being) formed to develop a sound scientific basis for recovery planning. Regional planners will use the information provided by the TRTs to craft comprehensive recovery plans for all listed ESUs within each domain. For more information about the ESA recovery planning process for salmon and steelhead and the TRTs, see the NMFS Northwest Salmon Recovery Planning web site (http://www.nwfsc.noaa.gov/cbd/trt/).

Recently, several factors led NMFS to conclude that the ESA status of listed salmon and steelhead ESUs should be reviewed at this time. First, a September 2001 court ruling called into question the NMFS decision to not list several hatchery populations considered to be part of the Oregon Coast coho salmon ESU (Alsea Valley Alliance v. Evans [161 F. Supp. 2d 1154, D. Oreg. 2001]; Alsea decision). The ruling held that the ESA does not allow listing of any unit smaller than a DPS (or ESU), and that NMFS had violated that provision of the act by listing only part of an ESU. Although this legal case applied directly only to the Oregon Coast coho salmon ESU, the same factual situation (hatchery populations considered part of listed ESUs, but not listed) also applied to most other listed ESUs of salmon and steelhead. Second, two additional lawsuits currently pending that involve California ESUs of steelhead (EDC v. Evans, SACV-00-1212-AHS (EEA); MID v. Evans, CIV-F-02-6553 OWW DLB (E.D. Cal)) raised a similar issue—NMFS concluded that resident fish were part of the ESU, but only the anadromous steelhead were listed. Again, this same factual situation is found in most, if not all, listed steelhead ESUs. Finally, at least several years of new data are available for most ESUs, and up to a decade has passed since the first populations were listed in the Sacramento and Snake Rivers. Furthermore, in some (but not all) areas, adult returns in the last few years have been considerably higher than have been seen for several decades.

As a result of these factors, NMFS committed to a systematic updating of the ESA status of all listed ESUs of Pacific salmon and steelhead (Federal Register Vol. 67, No. 28, February 11, 2002). This report summarizes updated biological information for the 26 listed salmon and steelhead ESUs and one candidate ESU (Lower Columbia coho salmon), and presents the Biological Review Team's (BRT's) conclusions regarding these ESUs' current risk status. The BRT consisted of a core group of scientists from the NMFS Northwest and Southwest Fisheries Science Centers, supplemented by experts on particular species from NMFS and other federal agencies. BRT membership is indicated in the sections for each species. The BRT met in January, March, and April 2003 to review information related to the updated status reviews.

ESU Determinations

As amended in 1978, the ESA allows listing of "distinct population segments" of vertebrates as well as named species and subspecies. However, the ESA provided no specific guidance for determining what constitutes a distinct population segment, and the resulting ambiguity led to the use of a variety of criteria in listing decisions over the past decade. To clarify the issue for Pacific salmon, NMFS published a policy describing how the agency will apply the definition of "species" in the ESA to anadromous salmonid species, including sea-run cutthroat trout and steelhead (NMFS 1991). A more detailed description of this topic appeared in the NMFS "Definition of Species" paper (Waples 1991). The NMFS policy stipulates that a salmon population (or group of populations) will be considered "distinct" for purposes of the ESA if it represents an ESU of the biological species. An ESU is defined as a population that: 1) is substantially reproductively isolated from conspecific population, and 2) represents an important component in the evolutionary legacy of the species. Information that can be useful in determining the degree of reproductive isolation includes incidence of straying, rates of recolonization, degree of genetic differentiation, and the existence of barriers to migration. Insight into evolutionary significance can be provided by data on genetic and life-history characteristics, habitat differences, and the effects of stock transfers or supplementation efforts. The NMFS BRTs have used a comprehensive approach that utilized all available scientific information to define ESUs. A discussion of how the NMFS policy was applied in a number of ESA status reviews can be found in Waples (1995).

Geographic Boundaries

The status review updates focused primarily on risk assessments, and (apart from the discussion of resident fish in steelhead ESUs) the BRT did not consider issues associated with the geographic boundaries of ESUs. If significant new information arises to indicate that specific ESU boundaries should be reconsidered, that would be done at a later time.

Artificial Propagation

Most salmon and steelhead ESUs have hatchery populations associated with them, and it is important for administrative, management, and conservation reasons to determine the biological relationship between these hatchery fish and natural populations within the ESU. The ESA status reviews conducted since 1993 have been guided by the NMFS ESA policy for artificial propagation of Pacific salmon and steelhead (NMFS 1993). That policy recognizes that "genetic resources important to the species' evolutionary legacy may reside in hatchery fish as well as in natural fish, in which case, the hatchery fish can be considered part of the "biological ESU in question." As part of the coastwide status reviews, the NMFS BRTs applied this principle in evaluating the ESU status of hatchery populations associated with all listed salmon and steelhead ESUs, with the result being that many hatchery populations are currently considered to be part of the ESUs. However, only a small fraction of these hatchery populations have been listed—generally, those associated with natural populations or ESUs considered at high risk of extinction. NMFS felt that listing other hatchery populations in the ESUs would provide little or no additional conservation benefit beyond that conferred by the listing of natural fish, but would greatly increase the regulatory burden on stakeholders, researchers, and the general public.

As discussed above, a recent court decision has determined that this approach is inconsistent with the act—an ESU must be listed or not listed in its entirety. At the same time that NMFS announced the status review updates, the agency committed to revising the ESA artificial propagation policy for Pacific salmon and using the revised policy to guide the hatchery ESU determinations and consideration of artificial propagation in the risk analyses (Federal Register Vol. 67, No. 28, February 11, 2002). Although a revised policy has not yet been proposed through formal rulemaking, a draft has been publicly available on the agency's web site since August 2002 (http://www.nwr.noaa.gov/HatcheryListingPolicy/DraftPolicy.pdf). That draft indicates that hatchery populations that have "diverged substantially from the evolutionary lineage represented by the ESU" will not be considered part of the ESU. The draft policy is currently under revision, and one issue that remains to be resolved is how "substantial" the divergence must be before a hatchery population should no longer be considered part of a salmon or steelhead ESU, even if it was originally derived from populations within the ESU. Due to the lack of resolution of this issue, the BRT has not attempted to revisit the ESU determinations for hatchery populations in this report. However, a separate working group has updated the stock histories and biological information for every hatchery population associated with each listed ESU (SSHAG 2003) and has also assigned each hatchery population to one of four categories, as described below. How these categories relate to ESU membership remains to be determined. A table showing the SSHAG categories appears in the Appendix to the section of the report for each species. The BRT reviewed the information in these appendices, along with other hatchery information, to obtain a better understanding of the nature and role of hatcheries associated with each listed ESU.

In the SSHAG document, each hatchery stock was assigned to a category based on variation across three axes (Figure 1): 1) the degree of genetic divergence between the hatchery stock and the natural population(s) that occupy the watershed into which the hatchery stock is released; 2) the origin of the hatchery stock; and 3) the status of the natural population(s) in the watershed. There are four categories of divergence: minimal, moderate, substantial, and extreme. Minimal divergence means that based on the best information available, there is no appreciable genetic divergence between the hatchery stock and the natural population(s) in the watershed (e.g., because the hatchery and wild populations are well mixed each generation). Moderate divergence means the level of divergence between the hatchery stocks and the local natural populations is no more than what would be expected between closely related populations within the ESU. Substantial divergence is roughly the level of divergence expected between more distantly related populations within the ESU. Extreme divergence is divergence greater than what would be expected among natural populations in the ESU, such as that caused by deliberate artificial selection or inbreeding. The second axis describes the origin of the hatchery stock, and can either be local, nonlocal but predominantly from within the ESU, or predominantly from outside of the ESU. The third axis describes the status of the natural population(s) in the watershed of the same species as the hatchery stock, which can either be native or nonnative.

Category 1 stocks are characterized by no more than minimal divergence between the hatchery stock and the local natural population(s) and regular, substantial incorporation of natural-origin fish into the hatchery broodstock. Within Category 1, Category 1a stocks are characterized by the existence of a native natural population of the same species in the watershed, while Category 1b stocks are characterized by the lack of such a population (i.e., the local naturally spawning population was introduced from elsewhere). Note that a Category 1a designation can describe a range of biological scenarios, and does not necessarily imply that the hatchery stock and the associated natural population are close to a “pristine” state. For example, a hatchery program that started many years ago with local broodstock and regularly incorporated local natural-origin fish in substantial proportions thereafter would likely be a Category 1a, even if both the hatchery stock and the local natural population have diverged from what the natural population was like historically.

Category 2 stocks are no more than moderately diverged from the local, natural population(s) in the watershed. Category 2a stocks were founded from a local, native population in the watershed in which they are released. Category 2b stocks were founded nonlocally but from within the ESU, and are released in a watershed that does not contain a native natural population. Category 2c stocks were founded nonlocally but from within the ESU, and are released in a watershed that contains a native natural population.

Category 3 stocks are substantially diverged from the natural population(s) in the watershed in which they are released. The “a”, “b,” and “c” designations are the same as described for Category 2 above.

Category 4 stocks characterized either by being founded predominantly from sources that are not considered part of the ESU in question, or by extreme divergence from the natural population(s) in the watershed in which they are released, regardless of founding source.

Source of hatchery stock and status of local population

relationship to natural population	source from local, native natural population	source non-local but within ESU, no native local natural population	source non-local but within ESU, native local natural population exists	source non-local and predominantly from outside of ESU
Substantial natural origin fish in broodstock and minimal divergence	1a	1b	NA	4
Moderate to few natural origin fish in broodstock and no more than moderate divergence *	2a	2b	2c	
substantial divergence **	3a	3b	3c	
extreme divergence ***	4	4	4	4

* moderate divergence = no more than observed between similar populations within ESU
** substantial divergence = comparable to divergence observed within entire ESU
*** extreme divergence = greater than divergence observed within ESU or substantial artificial selection or manipulation

Figure 1. Summary of hatchery categorization system (SSHAG 2003).

Resident Fish

In addition to the anadromous life history, sockeye salmon (*O. nerka*) and steelhead (*O. mykiss*) have nonanadromous or resident forms, generally referred to as kokanee and rainbow trout, respectively. (At least one resident population of chinook salmon also occurs, in Lake Cushman, Washington.) As is the case with hatchery fish, it is important to determine the relationships of these resident fish to anadromous populations in listed ESUs. This issue is complicated by the complexity of jurisdictional responsibilities—NMFS has ESA responsibility for anadromous Pacific salmonids, but the U.S. Fish and Wildlife Service (USFWS) has ESA jurisdiction for resident fish. At the time this report was prepared, the two agencies had not developed a general policy on how to determine the ESU/DPS status of resident fish or how to make the listing determinations for the overall ESU/DPSs.

Resident (kokanee) populations in the two ESA-listed sockeye salmon ESUs (Redfish Lake and Lake Ozette) have been genetically characterized and determined not to be part of the sockeye salmon ESUs. However, the ESU status of many resident populations of *O. mykiss* remains in doubt. For the purposes of this status review update, therefore, the BRT adopted a working framework for determining the ESU/DPS status of *O. mykiss* that are geographically associated with listed steelhead ESUs. These evaluations were guided by the same biological principles used to define ESUs of natural fish and determine ESU membership of hatchery fish: the extent of reproductive isolation from, and evidence of biological divergence from, other populations within the ESU. These principles are comparable to the “discreteness” and “significance” criteria of the joint DPS policy of the two listing agencies (61 FR 4722, 7 February 1996). Ideally, each resident population would be evaluated individually on a case-by-case basis using all available biological information. In practice, little or no information is available for most resident salmonid populations.

To facilitate conclusions about the ESU/DPS status of resident fish, NMFS and USFWS have identified three different cases, reflecting the range of geographic relationships between resident and anadromous forms within different watersheds:

Case 1: No obvious physical barriers to interbreeding exist between resident and anadromous forms.

Case 2: Long-standing natural barriers (e.g., a waterfall) separate resident forms upstream from anadromous forms downstream.

Case 3: Relatively recent (e.g., within last 100 years) human actions or man-made barriers (e.g., construction of a dam without provision for upstream fish passage) separate resident and anadromous forms.

The BRT reviewed available information about individual resident populations of *O. mykiss* to determine which case each population fits into. The BRT also adopted, for the purpose of the updated status reviews and extinction risk assessments, the following working assumptions about ESU membership of resident *O. mykiss* falling in each of these categories:

Case 1: Resident fish were assumed provisionally to be part of the ESU. Rationale: Empirical studies show that resident and anadromous *O. mykiss* are typically very similar genetically when they co-occur in sympatry, with no physical barriers to migration or interbreeding (Chilcote 1976, Currens et al. 1987, Leider et al. 1995, Pearsons et al. 1998). (Note: This assumption is not necessarily applicable to *O. nerka*, because sockeye and kokanee can show substantial divergence, even in sympatry.)

Case 2: Resident fish were assumed provisionally not to be part of the ESU. Rationale: Many populations in this category have been isolated from contact with anadromous populations for thousands of years. Empirical studies (Chilcote 1976, Currens et al. 1990) show that, in these cases, the resident fish typically show substantial genetic and life-history divergence from the nearest downstream anadromous populations.

Case 3: No default assumption was made about ESU status of resident fish.

The default assumptions about ESU membership for Case 1 and Case 2 populations can be overridden by specific information for individual populations. For example, as noted above, anadromous and resident *O. nerka* can diverge substantially in sympatry, and it is possible the same may be true for some *O. mykiss* populations.

The BRT discussed Case 3 populations at some length. Case 3 populations were, most likely, Case 1 populations (and hence presumably part of the ESU) prior to construction of the artificial barrier. Some BRT members felt that, in the absence of information to the contrary, it is reasonable to assume that Case 3 populations of *O. mykiss* are still in the ESU, given that the time since erection of the artificial barriers has been relatively short for substantial evolutionary divergence. However, the majority of the BRT members preferred to make no particular assumption regarding Case 3 populations. They reached this conclusion for two major reasons. First, Case 3 populations that historically were part of the ESU may no longer represent the ESU biologically because of (a) bottlenecks and/or local adaptation and rapid evolutionary divergence in a novel environment; or (b) displacement or introgression from nonnative, hatchery-origin rainbow trout. Notably, releases of hatchery rainbow trout have been widespread in the Pacific Northwest and California, including areas impounded by dams that block access to anadromous fish (Ludwig 1995, Van Vooren 1995). Empirical studies (Wishard et al. 1984, Williams et al. 1997, Utter 2001) have shown that the results of such releases can be quite variable, ranging from replacement of the native gene pool to hybridization to no detectable genetic effect. Therefore, the current relationship between Case 3 populations and anadromous populations in the ESU is difficult to evaluate without empirical data and historical stocking records for the population in question. Second, identifying a default assumption for Case 3 populations in the face of considerable biological uncertainty requires consideration of other factors that are not entirely scientific (such as, What is the appropriate burden of proof? and What are the biological, economic, and political consequences of making a wrong assumption?). Therefore, in this report the BRT did not suggest a default assumption regarding the ESU status of Case 3 populations. Instead, this report summarizes empirical information that does exist for specific Case 3 populations and discusses its relevance to ESU determinations. As new biological information relevant to the ESU status of individual Case 3 populations is developed as part of the overall recovery planning process for West Coast salmon and steelhead described in the Background and Introduction section, that information will be passed on to NMFS Regional Office Staff for consideration.

Genetic data can provide a powerful means for determining the evolutionary origin of a sampled population, and such data can therefore be very useful in evaluating the extent to which native resident *O. mykiss* populations have been affected by releases of nonnative hatchery rainbow trout. The steelhead ESU reports in Section B of this report summarize this information as it applies to specific Case 3 populations. As discussed above, rapid genetic changes associated with human impacts can also occur within populations in the absence of stock transfers, and these changes are unlikely to be detected with standard molecular genetic techniques. Evaluating the importance of such effects is very difficult. Phenotypic and life-history traits can serve as proxies for genetically based, adaptive differences among populations; however, such traits can also be affected by environmental conditions, which confounds their interpretation. These confounding effects can generally be teased apart only with very detailed experiments. It is therefore likely that the evolutionary relationships of many Case 3 populations will remain uncertain for the foreseeable future.

In response to a request for additional information about listed ESUs of steelhead (67 FR 79898-79900; 31 December 2002), NMFS received two comments relevant to the ESU status of resident *O. mykiss*. The Center for Biological Diversity (CBD 2003) argued that NMFS erred in referring to *O. mykiss* trapped above dams as “resident” fish and excluding them from the steelhead listings. According to CBD, the distinction between anadromous and resident populations should be based not on circumstances of geography (i.e., whether the fish are currently above or below a recent man-made barrier), but rather on biological attributes of the populations—specifically, the “genetic trait expressed in smoltification.” They argued that resident populations that are genetically (i.e., historically) anadromous, but which are currently trapped above human barriers with no opportunity to express anadromy, should be considered part of the listed steelhead ESUs. The BRT’s conclusions regarding the ESU status of Case 3 resident populations (above human barriers) is described above.

Trout Unlimited (2003) argued that, based on substantial ecological and life history differences, anadromous and resident *O. mykiss* should be in separate ESUs, even in cases where there are no appreciable molecular genetic differences between the two forms. They cited studies showing a) little evidence that transplanted rainbow trout can give rise to anadromous populations, and b) one study in the Deschutes River, in which all anadromous fish examined were found to have an anadromous female parent and all resident fish examined were found to have a resident female parent, as evidence for a genetic basis for the differences between the two forms. This argument is similar to the arguments the BRT has considered in previous status reviews, that summer and winter steelhead, or spring and fall chinook in coastal basins, should be in different ESUs (Busby et al. 1996; Myers et al. 1998). As in those status reviews, the BRT does not dispute that the two forms of *O. mykiss* can exhibit some degree of reproductive isolation, even in areas where they co-occur. However, the strong genetic similarity of the two forms in sympatry in every case where they have been examined indicates that, in general, the two forms are genetically linked on evolutionary time frames. Furthermore, the Deschutes River study (Zimmerman and Reeves 2000) also examined a population in British Columbia, where the authors found that anadromous fish can give rise to resident offspring, and vice versa—a result that has been found in other areas as well. In general, genetic data show that resident and anadromous *O. mykiss* below barriers in the same basin are genetically more similar to each other than either is to the same form in another basin. Therefore, lumping steelhead and resident populations into separate ESUs would create artificial units in which each population had its nearest relative in a different ESU. This problem could be resolved only by considering every population (anadromous or resident) its own ESU—a result that would lead to hundreds of ESUs of *O. mykiss* and would be inconsistent with the approach NMFS has taken in all other status reviews for Pacific salmon. Therefore, the BRT continued to consider the evolutionary relationships between resident and anadromous populations in a way that was consistent with the approach used in evaluating alternative life history forms in previous status reviews.

Although resident *O. mykiss* may occasionally produce anadromous offspring, and vice versa, there is (as noted by Trout Unlimited 2003) little empirical evidence to indicate that a population of resident *O. mykiss* can give rise to a self-sustaining anadromous *population*. This issue is relevant to extinction risk analysis for ESUs containing both forms and is discussed in Section B of this report.

Risk Assessments

ESA Definitions

After the composition of an ESA species is determined, the next question to address is, "Is the species threatened or endangered?" Section 3 of the ESA defines endangered species as "any species which is in danger of extinction throughout all or a significant portion of its range." The term threatened species is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." Neither NMFS nor the USFWS have developed formal policy guidance about how to interpret the ESA definitions of threatened or endangered species.

The BRT considers a variety of information in evaluating the level of risk faced by an ESU. According to Section 4 of the ESA, the determination of whether a species is threatened or endangered should be made "solely on the basis of the best scientific and commercial data available" regarding the species' current status, after taking into account efforts being made to protect the species. In its biological status reviews, the BRT does not evaluate possible future effects of protective efforts, except to the extent the effects are already reflected in metrics of population or ESU viability. Protective efforts are taken into account in a separate process by the NMFS regional offices prior to making listing determinations. Therefore, the BRT does not make recommendations as to whether identified ESUs should be listed as threatened or endangered species because that determination requires evaluation of factors not considered by the team. Rather, the BRT draws scientific conclusions about the current risk of extinction faced by ESUs, under the assumption that present conditions will continue into the future (recognizing, of course, that natural demographic and environmental variability are inherent features of "present conditions").

Factors for Decline

According to Section 4 of the ESA, the Secretary (of Commerce or the Interior) shall determine whether a species is threatened or endangered as a result of any (or a combination) of the following factors: destruction or modification of habitat; overutilization; disease or predation; inadequacy of existing regulatory mechanisms; or other natural or man-made factors. Collectively, these are often referred to as "factors for decline." In the Federal Register notices announcing the ESA listing decisions for West Coast salmon and steelhead, NMFS included sections identifying what have come to be known as the 4H factors for decline—habitat degradation and loss, hydropower development, overharvest, and hatchery propagation—as well as other factors. However, in the status reviews, the BRT did not attempt a rigorous analysis of this subject, and the same is true for this report. There are several reasons for this.

- First, the BRT chose to focus primarily on the question of whether an ESU is at risk rather than how it came to be at risk. Although the latter question is important, a population or ESU that has been reduced to low abundance will continue to be at risk for demographic and genetic reasons until it reaches a larger size, regardless of the reasons for its initial decline. Furthermore, in some cases, a factor that was important in causing the original declines may no longer be an impediment to recovery.

- Second, unlike many other ESA-listed species that face a single primary threat, salmon face a bewildering array of potential threats throughout every stage of their complex life cycle. It is relatively easy to simply enumerate current and past threats to salmon populations, but it is much more difficult to evaluate the relative importance of a wide range of interacting factors.
- Third, evaluating the degree to which historic factors for decline will continue to pose a threat in the future generally requires consideration of issues that are more in the realm of social science than biological science—such as whether proposed changes will be funded, and, if funded, will be implemented effectively.

In it's listing determination for the updated status reviews, NMFS will consider factors for decline and the extent to which they have been alleviated by protective efforts. It is expected that these issues will be addressed in detail in formal ESA recovery planning for ESUs that remain listed. The agency has outlined a two-step process for recovery planning; the first step is identifying biologically based delisting criteria, and the second step is developing a suite of actions (the Recovery Plan) that has a high probability of achieving the recovery goals. (For more information about ESA recovery planning for West Coast salmon and steelhead, visit http://www.nwfsc.noaa.gov/cbd/trt/about.htm.) Delisting would occur only after the ESU satisfied both the biological delisting criteria and associated administrative delisting criteria, which typically involve assurances that the threats to the continued existence of the ESU have been satisfactorily resolved.

Although this report does not consider factors for decline in a comprehensive way, the BRT did consider major risk factors that were identified in previous status reviews. The sections in this report focusing on specific ESUs summarize the previous BRT conclusions and identify any major changes in risk factors that have occurred since the time of listing.

Artificial Propagation

The 1993 NMFS ESA policy for artificial propagation of Pacific salmon and steelhead recognizes that artificial propagation can be one of the conservation tools used to help achieve recovery of ESA-listed species, but it does not consider hatcheries to be a substitute for conservation of the species in its natural habitat. Therefore, ESA risk analyses for salmon and steelhead ESUs were conducted for "natural" fish (which are defined as the progeny of naturally spawning fish), based on whether or not the natural populations can be considered self-sustaining without regular infusion of hatchery fish. This is the same provision articulated in the joint USFWS-NMFS policy on artificial propagation of all species under the ESA (Federal Register, Volume 65, Number 114, June 13, 2000, p. 37102) and is consistent with the approach the USFWS has used to evaluate captive propagation programs for other species, such as the condor (USFWS 1996) and the Bonytail chub (USFWS 2002).

The draft revised salmon hatchery policy outlines a three-step approach for considering artificial propagation in listing determinations:

1. Identify which hatchery populations are part of the ESU (see previous section).
2. Review the status of the ESU.
3. Evaluate existing protective efforts and make a listing determination.
4. This document is concerned with step 2—the risk analysis for listed salmon and steelhead ESUs.

The draft revised hatchery policy interprets the purpose of the ESA is to conserve threatened and endangered species in their natural habitats. In its risk evaluations, the BRT therefore used the approach it has in the past—focusing on whether populations and ESUs are self-sustaining in their natural habitat. In this report, therefore, when we refer to evaluations or conclusions of the BRT regarding the status of ESUs, we are referring to analyses conducted using the criterion of self-sustainability of natural populations.

Artificial propagation can be used as a conservation tool. Potential benefits of artificial propagation for natural populations include reducing the short-term risk of extinction, helping to maintain a population until the factors limiting recovery can be addressed, reseeding vacant habitat, and helping to speed recovery. Whether these potential benefits will be realized in any particular case is difficult to predict. To the extent that such benefits have already occurred, they will be reflected in the population abundance and trend data considered by the BRT. The draft revised hatchery policy also indicates that the potential future conservation benefits of artificial propagation should be considered before a listing determination is made. The potential conservation benefits of artificial propagation, together with other protective efforts, will be considered by NMFS regional office and headquarters staff in determining whether to propose any changes to the current ESA listing for West Coast salmon and steelhead.

Artificial propagation is important to consider in ESA evaluations of anadromous Pacific salmonids for several other reasons. First, although natural fish are the subject of risk assessments, possible positive or negative effects of artificial propagation on natural populations must also be evaluated. For example, artificial propagation can alter life-history characteristics such as smolt age and migration and spawn timing. Second, in addition to the potential to increase abundance of fish, artificial propagation poses a number of risks to natural populations that may affect their risk of extinction or endangerment. In contrast to most other types of risk for salmon populations, those arising from artificial propagation are often not reflected in traditional indices of population abundance. For example, to the extent that habitat degradation, overharvest, or hydropower development have contributed to a population's decline, these factors will already be reflected in population abundance data and accounted for in the risk analysis. The same is not necessarily true of artificial propagation. Hatchery production may mask declines in natural populations that will be missed if only raw population abundance data are considered. Therefore, a true assessment of the viability of natural populations cannot be attained without information about the genetic and demographic contribution of naturally spawning hatchery fish. Furthermore, even if such data are available, they will not in themselves provide direct information about possible deleterious effects of fish culture. Such an evaluation requires consideration of the genetic and demographic risks of artificial propagation for natural populations.

Resident Fish

As indicated above, the BRT concluded in previous status reviews that at least some resident *O. mykiss* populations belonged to steelhead ESUs, and these resident fish were considered in the overall risk analyses for those ESUs. However, in most cases, little or no information was available about the numbers and distribution of resident fish, as well as about the extent and nature of their interactions with anadromous populations. Given this situation, the previous risk analyses for steelhead ESUs focused primarily on the status of anadromous populations.

In these updated status reviews, increased efforts have been made to gather biological information for resident *O. mykiss* populations to assist in the risk analyses. (Although the two listed sockeye salmon ESUs considered in this report [Redfish Lake and Lake Ozette] have associated kokanee populations, in neither case are the kokanee considered to be part of the sockeye salmon ESU, so the kokanee were not formally considered in the risk analyses.) Information on resident fish is summarized below in the report for steelhead (Section B), where ESU-specific information is discussed in more detail. The steelhead report also contains a more general discussion of how resident fish were considered in the risk analyses for steelhead ESUs.

Factors Considered in Status Assessments

Salmonid ESUs are typically metapopulations; that is, they are usually composed of multiple populations with some degree of interconnection, at least over evolutionary time periods. This makes the assessment of extinction risk difficult. The approach to this problem that NMFS adopted for recovery planning is outlined in the viable salmonid populations (VSP) report (McElhany et al. 2000). In this approach, risk assessment is addressed at two levels: first, the population level, then at the overall ESU level. We have modified previous BRT approaches to ESU risk assessments to incorporate VSP considerations.

Individual populations are assessed according to the four VSP criteria: abundance, growth rate/productivity, spatial structure, and diversity. The condition of individual populations is then summarized on the ESU level, and larger-scale issues are considered in evaluating the status of the ESU as a whole. These larger-scale issues include total number of viable populations, geographic distribution of these populations (to ensure inclusion of major life-history types and to buffer the effects of regional catastrophes), and connectivity among these populations (to ensure appropriate levels of gene flow and recolonization potential in case of local extirpations). These considerations are detailed in McElhany et al. (2000).

In previous status reviews, the BRTs have used a simple “risk matrix” for quantifying ESU-scale risks according to major risk factors. The revised matrix (Table 1) integrates the four major VSP criteria (abundance, productivity, spatial structure, and diversity) directly into the risk assessment process. After reviewing all relevant biological information for a particular ESU, each BRT member assigns a risk score (see below) to each of the four VSP criteria. Use of the risk matrix makes it easier to compare risk factors within and across ESUs. The scores are tallied and reviewed by the BRT before making its overall risk assessment (see FEMAT method, below). Although this process helps to integrate and quantify a large amount of diverse information, there is no simple way to translate the risk matrix scores directly into an assessment of overall risk. For example, simply averaging the values of the various risk factors would not be appropriate; an ESU at high risk for low abundance would be at high risk even if there were no other risk factors.

Scoring VSP criteria. Risks for each VSP factor are ranked on a scale of 1 (very low risk) to 5 (very high risk):

1. *Very Low Risk.* Unlikely that this factor contributes significantly to risk of extinction, either by itself or in combination with other factors.
2. *Low Risk.* Unlikely that this factor contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.
3. *Moderate Risk.* This factor contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.
4. *High Risk.* This factor contributes significantly to long-term risk of extinction and is likely to contribute to short-term risk of extinction in the foreseeable future.
5. *Very High Risk.* This factor by itself indicates danger of extinction in the near future.

Recent events. The “recent events” category considers events that have predictable consequences for ESU status in the future but have occurred too recently to be reflected in the population data. Examples include a flood that decimated most eggs or juveniles in a recent broodyear, or large jack returns that generally anticipate strong adult returns in subsequent year(s). This category is scored as follows:

++ — expect a strong improvement in status of the ESU;

\+ — expect some improvement in status;

0 — neutral effect on status;

\- — expect some decline in status;

-- — expect strong decline in status.

Table 1. Template for the risk matrix used in BRT deliberations. The matrix is divided into five sections that correspond to the four VSP "parameters" (McElhany et al. 2000) plus a "recent events" category.

[ESU Name]

Risk Category	**Score***
Abundance Comments:	
Growth Rate/Productivity Comments:	
Spatial Structure and Connectivity Comments:	
Diversity Comments:	
Recent Events	

* Rate overall risk of ESU on 5-point scale (1–very low risk; 2–low risk; 3–moderate risk; 4–increasing risk; 5–high risk), except recent events double plus (++, strong benefit) to double minus (--, strong detriment)

Historical distribution and abundance. The ESA has no provision that requires a species to occupy its entire historic habitat or reach historic levels of abundance before it can be considered no longer threatened or endangered. Using the VSP criteria described above, it is only necessary that an ESU contain enough viable populations and satisfy concerns for spatial structure and diversity. However, developing strictly quantitative viability criteria is extremely challenging, even at the population level (see "Methods"). Therefore, other approaches that provide insight into viability are also important to consider. If our definitions of ESUs (groups of populations on independent evolutionary trajectories) and populations (demographically independent units over at least a 100-year time frame) are correct, then by definition they were sustainable at historic levels. Therefore, we can be confident that a population or ESU that approximates its historic distribution and abundance will be viable into the future. This *a priori* presumption of viability diminishes the further the current status departs from the historical template. For a population or ESU that is greatly reduced from its historic distribution and/or abundance, there is little *a priori* reason to assume the current status is viable. The viability of such a population or ESU is in considerable doubt unless independent data can be developed to assess viability.

Marine productivity. In the last decade, evidence has accumulated to demonstrate (1) recurring, decadal-scale patterns of ocean-atmosphere climate variability in the North Pacific Ocean (Zang et al. 1997, Mantua et al. 1997), and (2) correlations between these oceanic productivity "regimes" and salmon population abundance in the Pacific Northwest and Alaska (Hare et al. 1999, Mueter et al. 2002). There seems to be little doubt that survival rates in the marine environment can be strong determinants of population abundance for Pacific salmon and steelhead. It is also generally accepted that for at least two decades, beginning about 1977, marine productivity conditions were unfavorable for the majority of salmon and steelhead populations in the Pacific Northwest (in contrast, many populations in Alaska attained record abundances during this period). Finally, there is evidence that an important shift in ocean-atmosphere condition occurred around 1998. One indicator of the ocean-atmosphere variation for the North Pacific is the Pacific Decadal Oscillation index (PDO); Figure 2 shows that the PDO has taken mostly negative values since 1999 (time period C on the graph), whereas the values were positive in most of the previous two decades (time period B) and generally negative again for a long period before that (period A). Negative PDO values are associated with relatively cool ocean temperatures (and generally high salmon productivity) off the Pacific Northwest, and positive values are associated with warmer, less productive conditions. As discussed in this report, increases in many salmon populations in recent years may be largely a result of more favorable ocean conditions.

Although these facts are relatively well established, much less certainty can be attached to any predictions about what this means for the viability of listed salmon and steelhead. For several reasons, considerable caution is needed to project into the future. First, empirical evidence for "cycles" in PDO, marine productivity, and salmon abundance extends back only about a century, or about three periods of two- to four-decades' duration. This is a very short data record for inferring future behavior of a complex system. Thus, as with the stock market, the past record is no guarantee of future performance. Second, the past decade has seen particularly wide fluctuations not only in climatic indices (e.g., the 1997–1998 El Niño was in many ways the most extreme ever recorded, and the 2000 drought was one of the most severe on record), but also in abundance of salmon populations. In general, as the magnitude of fluctuations increases, the population extinction rate also increases. Third, if there is anthropogenically caused climate change in the future, it could affect ocean productivity. The range of future climate change scenarios consistent with existing data is so wide that future consequences cannot be predicted with any certainty; however, many models suggest that northern latitudes are likely to experience significant temperature increases (IPCC 2001). Finally, changes in the pattern of ocean-atmosphere interactions do not affect all species (or even all populations of a given species) in the same way (Peterman et al. 1998).

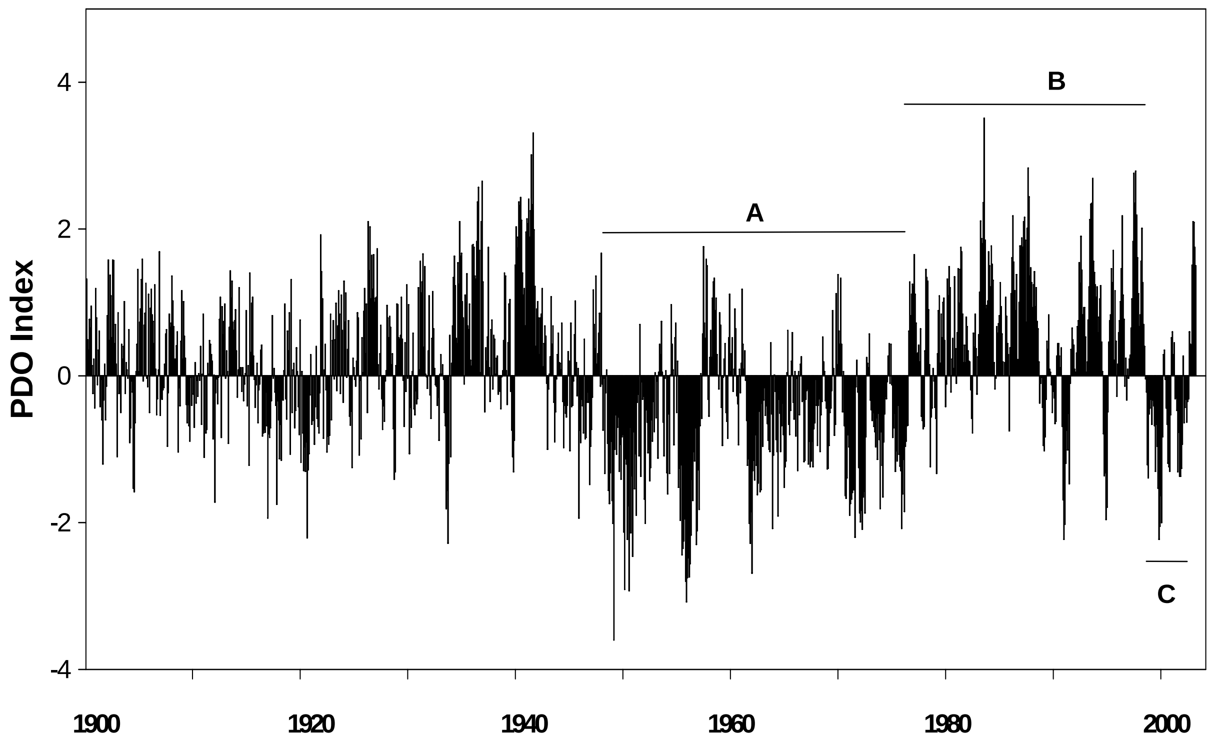

Figure 2. Monthly values for the Pacific Decadal Oscillation Index, which is based on sea surface temperatures in the North Pacific. Values shown are deviations from the long-term (1900–1993) mean. See text for discussion of time periods A, B, and C. (From http://tao.atmos.washington.edu/pdo/)

Based on these considerations, the BRT identified a number of possible future scenarios for impacts of ocean productivity on listed salmon and steelhead populations:

1. The PDO index could remain primarily negative for another decade or two (a typical duration for “regimes” observed in the past), leading to marine productivity conditions that are generally more favorable to Pacific Northwest salmon and steelhead than occurred from the mid-1970s to the late 1990s.
2. The last several years might be an anomaly, and the PDO index might revert back to the positive regime it has largely been in since the mid 1970s. It is worth noting in this regard that the PDO index has been positive in every month from August 2002 through March 2003 (Figure 2).

3. Marine and freshwater systems may continue to see wide fluctuations in environmental conditions.
4. Anthropogenically caused climate change might be a significant factor in the future, with consequences that are difficult to predict.

Given all these uncertainties, the BRT was reluctant to make any specific assumptions about the future behavior of the ocean-atmospheric systems or their effects on the distribution and abundance of salmon and steelhead. The BRT was concerned that even under the most optimistic scenario (a), increases in abundance might be only temporary and could mask a failure to address underlying factors for decline. The real conservation concern for West Coast salmon and steelhead is not how they perform during periods of high marine survival, but how prolonged periods of poor marine survival affect the VSP parameters of abundance, growth rate, spatial structure, and diversity. It is reasonable to assume that salmon populations have persisted over time, under pristine conditions through many such cycles in the past. Less certain is how the populations will fare in periods of poor ocean survival when their freshwater, estuary, and nearshore marine habitats are degraded.

Overall Risk Assessment

The BRT analysis of overall risk to the ESU uses categories that correspond to definitions in the ESA: in danger of extinction, likely to become endangered in the foreseeable future, or neither. (As discussed above, these evaluations do not consider protective efforts and therefore are not recommendations regarding listing status.) The overall risk assessment reflects professional judgment by each BRT member. This assessment is guided by the results of the risk matrix analysis as well as expectations about likely interactions among factors. For example, a single factor with a “high risk” score might be sufficient to result in an overall score of “in danger of extinction,” but a combination of several factors with more moderate risk scores could also lead to the same conclusion.

To allow for uncertainty in judging the actual risk facing an ESU, the BRT has adopted a “likelihood point” method, often referred to as the “FEMAT” method because it is a variation of a method used by scientific teams evaluating options under President Clinton’s Forest Plan (Forest Ecosystem Management: An Ecological, Economic, and Social Assessment Report of the Forest Ecosystem Management Assessment Team [FEMAT; http://www.or.blm.gov/ForestPlan/NWFPTitl.htm]). In this approach, each BRT member distributes ten likelihood points among the three ESU risk categories, reflecting their opinion of how likely that category correctly reflects the true ESU status. Thus, if a reviewer were certain that the ESU was in the “not at risk” category, he or she could assign all ten points to that category. A reviewer with less certainty about ESU status could split the points among two or even three categories. This method has been used in all status review updates for anadromous Pacific salmonids since 1999.

METHODS

Primary contributors: Thomas P. Good and Sarah Sydor
(Northwest Fisheries Science Center)

Data on abundance, the fraction of hatchery-origin spawners, harvest, age structure, and hatchery releases were requested from state, federal and tribal sources [Federal Register, Vol. 67, No. 28, February 11, 2002, p. 6215] and were compiled with previous data to conduct updated risk analyses for each ESU. Data on adult returns were obtained from a variety of sources, including time series of freshwater spawner surveys, redd counts, and counts of adults migrating past dams/weirs. Time series were assembled and analyzed at the scale of VSP populations where these have been identified by Technical Recovery Teams (TRTs) or “quasi-populations” where populations are in the process of being identified by TRTs.

Preliminary data and analyses were reviewed by state, federal, and tribal comanagers for accuracy and completeness. Where possible, population or ESU-level estimates of the fraction of hatchery-origin spawners were obtained or calculated using information from scale analyses, fin clips, etc. Estimates of harvest were obtained for some stocks directly; for others, harvest rates on nearby indicator stocks were used to estimate the number of fish in the target population that would have returned to spawn in the absence of harvest. See appendices at the end of each species section for detailed information and references for data sources.

Recent abundance

Recent abundance of natural spawners is reported as the geometric mean (and range) of the most recent data to be consistent with previous coast-wide status reviews of these species (Weitkamp et al. 1995, Busby et al. 1996, Gustafson et al. 1997, Johnson et al. 1997, Myers et al. 1998). Geometric means were calculated to represent the recent abundance of natural spawners for each population or quasi-population within an ESU. Geometric means were calculated for the most recent five years (chinook, steelhead), four years (chum, sockeye), or three years (coho); these time frames were selected to correspond with modal age at maturity for each species. Zero values in the data set were replaced with a value of one, and missing data values within a multiple-year range were excluded from geometric mean calculations. The geometric mean is the *n*th root of the product of the *n* data:

$$\bar{X}_G = \sqrt[n]{N_1 N_2 N_3 ... N_n}\ , \qquad \text{(Eq. 1)}$$

where N_t is the abundance of natural spawners in year *t*.

Arithmetic means (and ranges) were also calculated for the most recent abundance data:

$$\bar{X}_A = \frac{\sum N_i}{n}\ , \qquad \text{(Eq. 2)}$$

where N_t is the abundance of natural spawners in year *t*.

Trends in abundance

Short-term and long-term trends were calculated from time series of the total number of adult spawners. Short-term trends were calculated using data from 1990 to the most recent year, with a minimum of 10 data points in the 13-year span. Long-term trends were calculated using all data in a time series.

Trend was calculated as the slope of the regression of the number of natural spawners (log-transformed) over the time series; to mediate for zero values, one was added to natural spawners before transforming the data. Trend was reported in the original units as exponentiated slope, such that a value > 1 indicates a population trending upward, and a value < 1 indicates a population trending downward. The regression was calculated as

$$\ln(N+1) = \beta_0 + \beta_1 X + \varepsilon\,, \qquad \text{(Eq. 3)}$$

where N is the natural spawner abundance, β_0 is the intercept, β_1 is the slope of the equation, and ε is the random error term.

Confidence intervals (95%) for the slope, in their original units of abundance, were calculated as

$$\exp(\ln(b_1) - t_{0.05(2),df}\, s_{b_1}) \le \beta_1 \le \exp(\ln(b_1) + t_{0.05(2),df}\, s_{b_1})\,, \qquad \text{(Eq. 4)}$$

where b_1 is the estimate of the true slope β_1, $t_{0.05(2),\,df}$ is the two-sided t-value for a confidence level of 0.95, df is equal to n-2, n is the number of data points in the time series, and s_{b1} is the standard error of the estimate of the slope, b_1. The probability that the trend value was declining [P(trend < 1)] was also calculated.

Population growth rate

In addition to analyses of trends in natural spawners, we calculated the median short-term population growth rate (λ) of natural-origin spawners as a measure for comparative risk analysis. Lambda more accurately reflects the biology of salmon and steelhead, as it incorporates overlapping generations and calculates running sums of cohorts. It is an essential parameter in viability assessment, as most population extinctions are the result of steady declines, $\lambda < 1$. It has been developed for data sets with high sampling error and age-structure cycles (Holmes 2001). These methods have been extensively tested using simulations for both threatened and endangered populations as well as for stocks widely believed to be at low risk (Holmes, in press), and cross-validated with time series data (Holmes and Fagan 2002).

The λ of natural-origin spawners was calculated in two ways for each population over the short-term time frame (1990-most recent year). The first (λ) assumed that hatchery-origin spawners had zero reproductive success, while the second (λ_h) assumed that hatchery-origin spawners had reproductive success equivalent to that of natural-origin spawners. These extreme assumptions bracket the range likely to occur in nature. Empirical studies indicate that hatchery-origin spawning fish generally have lower (and perhaps much lower) reproductive success than natural-origin spawners (reviewed by Reisenbichler and Rubin 1999). However, this difference can vary considerably across species and populations, and it is very rare that data are available for a particular population of interest. Therefore, to be conservative, we bracketed the scenarios that are likely to be occurring in nature.

A multi-step process based on methods developed by Holmes (2001), Holmes and Fagan (2002) and described in McClure et al. (in press) was used to calculate estimates for λ, its 95% confidence intervals, and its probability of decline [P(λ < 1)]. The first step was calculating 4-year running sums for natural-origin spawners as

$$R_t = \sum_{i=1}^{4} N_{t-i+1} . \qquad \text{(Eq. 5)}$$

where N_t is the number of natural-origin spawners in year *t*. A 4-year running sum window was used for all species, as analysis by McClure et al. (in press) indicates this is an appropriate window for a diverse range of species life histories.

Next, an estimate of μ, the rate at which the median of *R* increases through time (Holmes 2001), was calculated as

$$\hat{\mu} = mean\left(\ln\left(\frac{R_{t+1}}{R_t}\right)\right) \qquad \text{(Eq. 6)}$$

—the mean of the natural log-transformed running sums of natural-origin spawners. The point estimate for λ was then calculated as the median annual population growth rate,

$$\hat{\lambda} = e^{\hat{\mu}} . \qquad \text{(Eq. 7)}$$

Confidence intervals (95%) were calculated for $\hat{\lambda}$ to provide a measure of the uncertainty associated with the growth rate point estimate. First, an estimate of variability for each population was determined by calculating an estimate for σ^2_{pop} using the slope method (Holmes 2001). The slope method formula is

$$\hat{\sigma}^2_{pop} = \text{slope of var}\left(\ln\left(\frac{R_{t+\tau}}{R_t}\right)\right) \text{vs.}\,\tau., \qquad \text{(Eq. 8)}$$

where τ is a temporal lag in the time series of running sums.

Individual population variance estimates were highly uncertain, so a more robust variance estimate, σ^2_{avg}, was obtained by averaging the σ^2_{pop} estimates from all the populations in an ESU. This average variance estimate was then applied as the variance for every population in an ESU. The degrees of freedom associated with the average variance estimate are obtained by summing the degrees of freedom for each of the individual population variance estimates. The degrees of freedom for the individual population estimates were determined using the method of Holmes and Fagan (2002), which identifies the adjusted degrees of freedom associated with slope method variance estimates. The calculation for the adjusted degrees of freedom is

$$df = 0.212n - 1.215, \qquad \text{(Eq. 9)}$$

where n is the length of the time series. Using the average variance estimate and the summed degrees of freedom, the 95% confidence intervals for λ were calculated as

$$\exp\left(\hat{\mu} \pm t_{.05(2),df} \sqrt{\hat{\sigma}_{slp}{}^{2} / (n-4)}\right). \qquad \text{(Eq. 10)}$$

In addition, the probability that the population growth rate was declining [P(λ < 1)] was calculated utilizing the fact that ln(λ) follows a *t*-distribution. This probability is calculated by finding the probability that the natural log of the calculated lambda divided by its standard error is less than zero.

The preceding treatment ignores contributions of hatchery-origin spawners to the next generation, in effect assuming that they had zero reproductive success. This assumption produces the most optimistic view of viability of the natural population. The other extreme assumption (that hatchery-origin spawners have reproductive success equivalent to that of natural-origin spawners), produces the most pessimistic view of viability of the natural population, given any particular time series of data. To calculate the median growth rate under this assumption (λ_h), a modified approach to the method developed by Holmes (2001) was used to calculate estimates for λ_h, 95% confidence intervals for λ_h, and to determine $P(\lambda_h < 1)$. The first step was calculating 4-year running sums (*RN*) for natural-origin spawners as

$$(RN)_t = \sum_{i=1}^{4} N_{t-i+1}\ . \qquad \text{(Eq. 11)}$$

Next, the 4-year running sum of hatchery-origin spawners was calculated as

$$(RH)_t = \sum_{i=1}^{4} H_{t-i+1}\ , \qquad \text{(Eq. 12)}$$

where H_t is the number of hatchery spawners in year t.

The ratio of total spawners to natural origin spawners was calculated as

$$\psi_t = \frac{(RN)_t + (RH)_t}{(RN)_t}. \qquad \text{(Eq. 13)}$$

The average age at reproduction, *T*, was calculated in three steps:

1. Determine the total number of spawners for each age (*A*) by calculating

$$A_j = \sum_{j=1}^{\max age} \sum_{all\ t} a_j (N+H)_t . \quad \text{(Eq. 14)}$$

2. Calculate the total number of spawners (*G*)

$$G = \sum_{j=1}^{\max age} A_j . \quad \text{(Eq. 15)}$$

3. Determine the average age at reproduction (*T*) by calculating

$$T = \sum_{j=1}^{\max age} \frac{j \times A_j}{G} . \quad \text{(Eq. 16)}$$

Next, an estimate of μ, the rate at which the median increases through time (Holmes 2001), was calculated as

$$\hat{\mu} = mean\left(\ln\left(\frac{(RN)_{t+1}}{(RN)_t} \right) - \frac{1}{T} \ln(\psi_t) \right). \quad \text{(Eq. 17)}$$

The point estimate for λ_h was then calculated as the median annual population growth rate (Eq. 7).

Confidence intervals (95%) for λ_h and its probability of decline [$P(\lambda_h < 1)$] were calculated as for λ, with modification to the slope method for calculating the variance:

$$\hat{\sigma}^2 = \text{slope of var}\left(\ln\left(\frac{(RN)_{t+\tau}}{(RN)_t} \right) - \frac{1}{T} \ln\left(\prod_{i=0}^{\tau-1} \psi_{t+i} \right) \right) \text{vs.}\, \tau. \quad \text{(Eq. 18)}$$

Calculating recruits

Recruits, or spawners in the next generation, from a give brood year were calculated as

$$C_t = \sum_{i=1}^{MaxAge} N_{t+i} A(i)_{t+i} , \quad \text{(Eq. 19)}$$

where C_t is the number of recruits from brood year *t*, N_t is the number of natural origin spawners in year *t*, and $A(i)_t$ is the fraction of age *i* spawners in year *t*. The estimate of preharvest recruits is similarly

$$C(preHarvest)_t = \sum_{i=1}^{MaxAge} P_{t+i} A(i)_{t+i} , \quad \text{(Eq. 20)}$$

where $C(preHarvest)_t$ is the number of preharvest recruits in year t, P_t is the number of natural origin spawners that would have returned in year t if there had not been a harvest, and $A(i)_t$ is the fraction of age i spawners in year t had there not been a harvest. [Because P_t is in terms of the number of fish that would have appeared on the spawning grounds had there not been a harvest, it can be quite difficult to estimate and simplifying assumptions are often made].

Population Viability Analysis

A variety of quantitative approaches to Population Viability Analysis (PVA) have been used with Pacific salmonids. Because no consensus has emerged on how best to model population viability in salmon, we did not employ a standardized PVA model in this report. However, we considered results of PVA analyses that had been conducted for specific populations.

REFERENCES

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-27, 261 p.

CBD (Center for Biological Diversity). 2003. Letter from David Hogan to Rodney McInnis re: Status review updates for Snake River sockeye salmon and southern California steelhead: and additional information request for nine ESUs of west coast steelhead. February 14, 2003. 4 p.

Chilcote, M. W. 1976. Genetic comparison of Deschutes River steelhead and rainbow trout at selected enzyme loci. M. S. Thesis, Oregon State Univ., Corvallis, OR.

Currens, K. P., S. L. Stone, and C. B. Schreck. 1987. A genetic comparison of rainbow trout (*Salmo gairdneri*) above and below Izee Falls in the John Day River, Oregon. Oregon Coop. Fish. Res. Unit Genet. Lab. Rep. 87(2), 34 p. (Available from Oregon Cooperative Fishery Research Unit, Oregon State University, Corvallis, OR 97331.)

Currens, K. P., C. B. Schreck, and H. W. Li. 1990. Allozyme and morphological divergence of rainbow trout (*Oncorhynchus mykiss*) above and below waterfalls in the Deschutes River, Oregon. Copeia 1990:730-746.

Gustafson, R. G., T. C. Wainwright, G. A. Winans, F. W. Waknitz, L. T. Parker, and R. S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-33, 282 p.

Holmes, E. 2001. Estimating risks in declining populations with poor data. Proceedings of the National Academy of Sciences: 98(9): 5072-5077.

Holmes, E. E. and W. F. Fagan. 2002. Validating population viability analysis for corrupted data sets. Ecology 83: 2379-2386.

IPPC (Intergovernmental Panel on Climate Change). 2001. Climate change 2001: impacts, adaptation, and vulnerability. Cambridge University Press, New York, NY.

Johnson, O.W., W. S. Grant, R.G. Kope, K. Neely, F.W. Waknitz, and R. S. Waples. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-32, 280 p.

Kostow, K. 2003. The biological implications of non-anadromous *Oncorhynchus mykiss* in Columbia River Basin steelhead ESUs. Draft report to the National Marine Fisheries Service. January 13, 2003. 90 pp.

Leider, S. A., S. R. Phelps, and P. L. Hulett. 1995. Genetic analysis of Washington steelhead: Implications for revision of genetic conservation management units. Wash. Dep. Fish Wildl. Prog. Rep., 21 p. (Available from Washington Department of Fish and Wildlife, Fish Management Program, 600 Capitol Way N, Olympia, WA 98501-1091).

Ludwig, B. 1995. British Columbia's trout hatchery program and the stocking policies that guide it. Amer. Fish. Soc. Symposium 15:139-143.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78: 1069-1079.

McClure, M. M., E. E. Holmes, B. L. Sanderson, and C. E. Jordan. 2003. A large-scale, multi-species status assessment: anadromous salmonids in the Columbia River Basin. Ecological Applications (in press).

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U. S. Dept. Commer. NMFS-NWFSC-42.

Mueter, F. J., R. M. Peterman, and B. J. Pyper. 2002. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (*Oncorhynchus* spp.) in northern and southern areas. Can. J. Fish. Aquat. Sci. 59:456-463.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-35, 443 p.

NMFS (National Marine Fisheries Service). 1991. Notice of policy: Policy on applying the definition of species under the Endangered Species Act to Pacific salmon. Federal Register [Docket 910248-1255, 20 November 1991] 56(224): 58612-58618.

NMFS (National Marine Fisheries Service). 1993. Interim policy on artificial propagation of Pacific salmon under the Endangered Species Act. Federal Register [Docket 921186-2286, 5 April 1993] 58(63): 17573-17576.

Peterman, R. M., B. J. Pyper, M. F. Lapointe, M. D. Adkison, and C. J. Walters. 1998. Patterns of covariation in survival rates of British Columbian and Alaskan sockeye salmon (*Oncorhynchus nerka*) stocks. Can. J. Fish. Aquat. Sci. 55:2503-2517.

Pearsons, T. N., S. R. Phelps, S. W. Martin, E. L. Bartrand and G. A. McMichael. 1998. Gene flow between resident and anadromous rainbow trout in the Yakima Basin: ecological and genetic evidence. Project No. 89-105. Bonneville Power Administration, Portland, OR.

Reisenbichler, R. R. and S. P. Rubin. 1999. Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplemented populations. ICES Journal of Marine Science 56:459-466.

SSHAG (Salmon and Steelhead Hatchery Assessment Group). 2003. Hatchery Broodstock Summaries and Assessments for Chum, Coho, and Chinook Salmon and Steelhead stocks within Evolutionarily Significant Units listed under the Endangered Species Act. May 12, 2003. NMFS Northwest and Southwest Fisheries Science Centers.

Trout Unlimited. 2003. Letter from Kaitlin Lovell to James Lecky and Donna Darm re: Comments on information request for nine ESUs of west coast steelhead. February 15, 2003. 6 p.

USFWS (United States Fish and Wildlife Service). 1996. California Condor Recovery Plan, Third Revision. Portland, Oregon, 62 p.

USFWS (United States Fish and Wildlife Service). 2002. Bonytail *(Gila elegans*) Recovery Goals: amendment and supplement to the Bonytail Chub Recovery Plan. U.S.F.W.S., Mountain-Prairie Region (6), Denver, Colorado.)

Utter, F. M. 2001. Patterns of subspecific anthropogenic introgression in two salmonid genera. Rev. Fish Biol. Fish. 10:265-279.

Van Vooren, A.R. 1995. The roles of hatcheries, habitat, and regulations in wild trout management in Idaho. Amer. Fish. Soc. Symposium 15:512-517.

Waples, R. S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Mar. Fish. Rev. 53(3):11-22.

Waples, R. S. 1995. Evolutionarily significant units and the conservation of biological diversity under the Endangered Species Act. pp 8-27 in: J. L. Nielsen, ed. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society, Bethesda, MD.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-24. 258 p.

Williams, R. N., R. F. Leary and K. P. Currens. 1997. Localized genetic effects of a long-term hatchery stocking program on resident rainbow trout in the Metolius River, Oregon. N. Amer J. Fish. Man. 17: 1079-1093.

Wishard, L. N., J. E. Seeb, F. M. Utter and D. Stefan. 1984. A genetic investigation of suspected redband trout populations. Copeia 1984:120-132.

Zhang, Y., J.M. Wallace, and D.S. Battisti. 1997. ENSO-like interdecadal variability: 1900-93. J. Climate 10: 1004-1020.

Zimmerman, C. E. and G. H. Reeves. 2000. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otolith microchemistry. Can. J. Fish. Aquat. Sci. 57: 2152-2162.